Integration of intermittent renewable generation. The case of Denmark

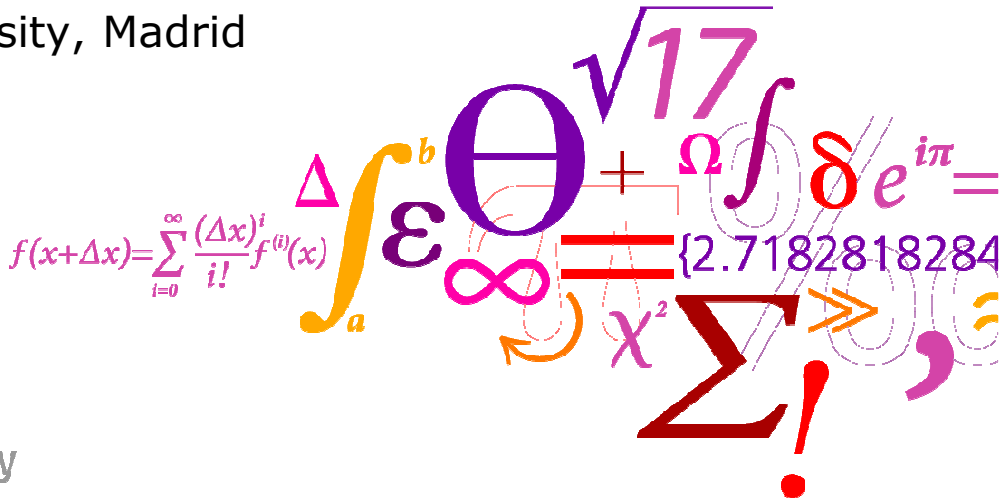
Jacobsen, Henrik

Publication date:
2010

Integration of intermittent renewable generation. The case of Denmark

Henrik Klinge Jacobsen
Energy Systems Analysis
Risø DTU

November 12, 2010
EES-UETP Course at Comillas University, Madrid



Risø DTU
National Laboratory for Sustainable Energy

Integration of intermittent renewable generation. The case of Denmark

AGENDA

- Intermittent generation in Denmark
- Power system and integration in the Nordic Market
- Wind shares in DK West- off shore wind parks
- Market prices and wind
- Wind power generation and revenue – the disadvantage relative to average

- Discussion of excess wind and the export revenue
- Why did the large wind shares integrate that easy?

- Future reliability and power plants being decommissioned due to excess capacity

Intermittent generation in Denmark 2010

Majority is wind power

3730 MW total

of which

- 2862 MW on shore
- 868 MW off shore

PV: 3MW

Total DK generation capacity: 13409 MW

A number of new off shore wind parks have been commissioned recently
Rødsand 2, Horns REV 2

18.3% of electricity consumption in DK from wind in 2009

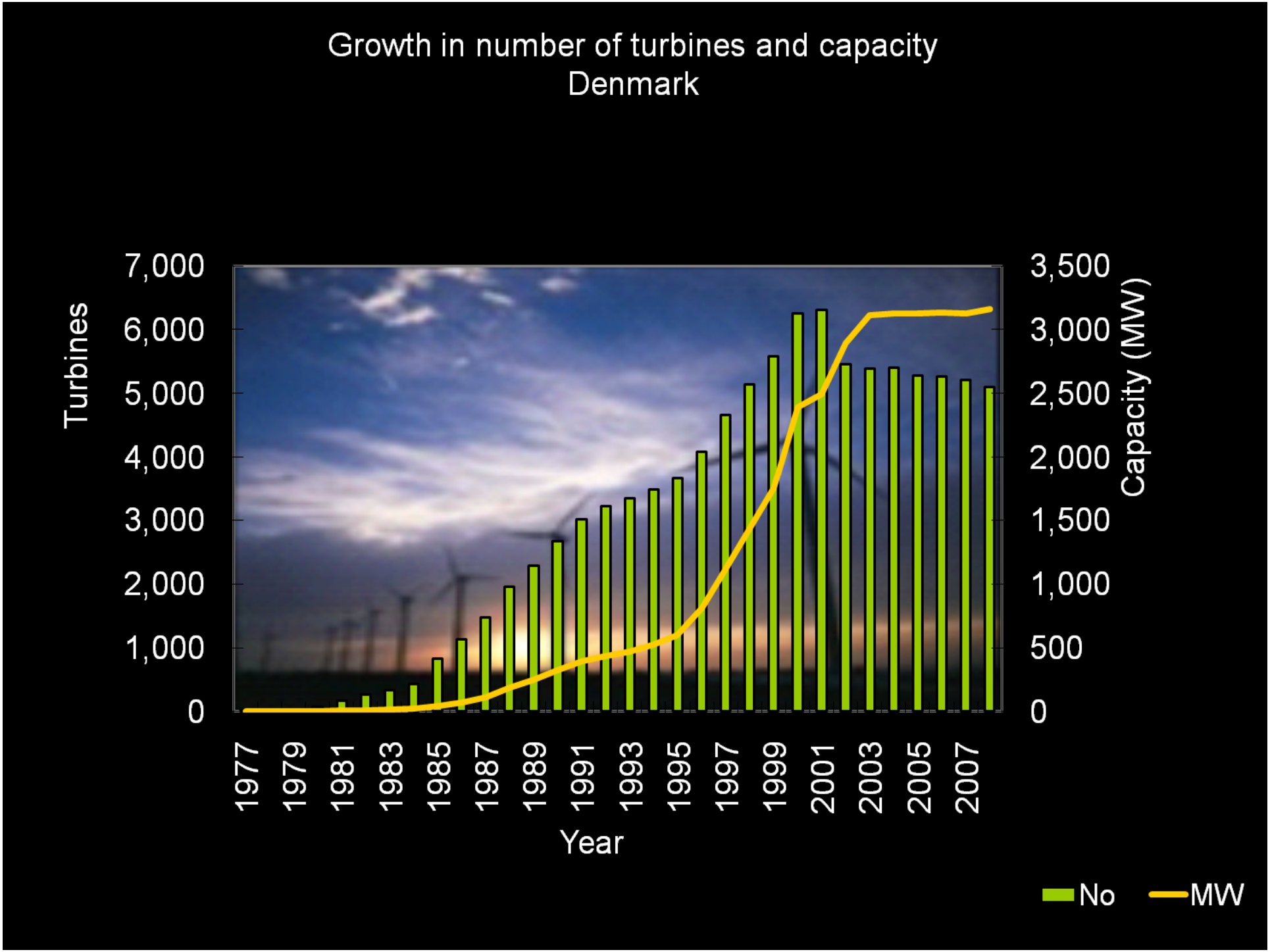
Not equally distributed: Western Denmark has the largest share: 2744 MW

422 MW is off-shore

5143 MW conventional in DK West

Peak load = 3677 MW

Plans are to increase considerably with mainly off-shore


Growth in number of turbines and capacity
Denmark
Turbines
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Capacity (MW)
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Year
No
MW

DK is a transit system from the north Hydro to continental Europe

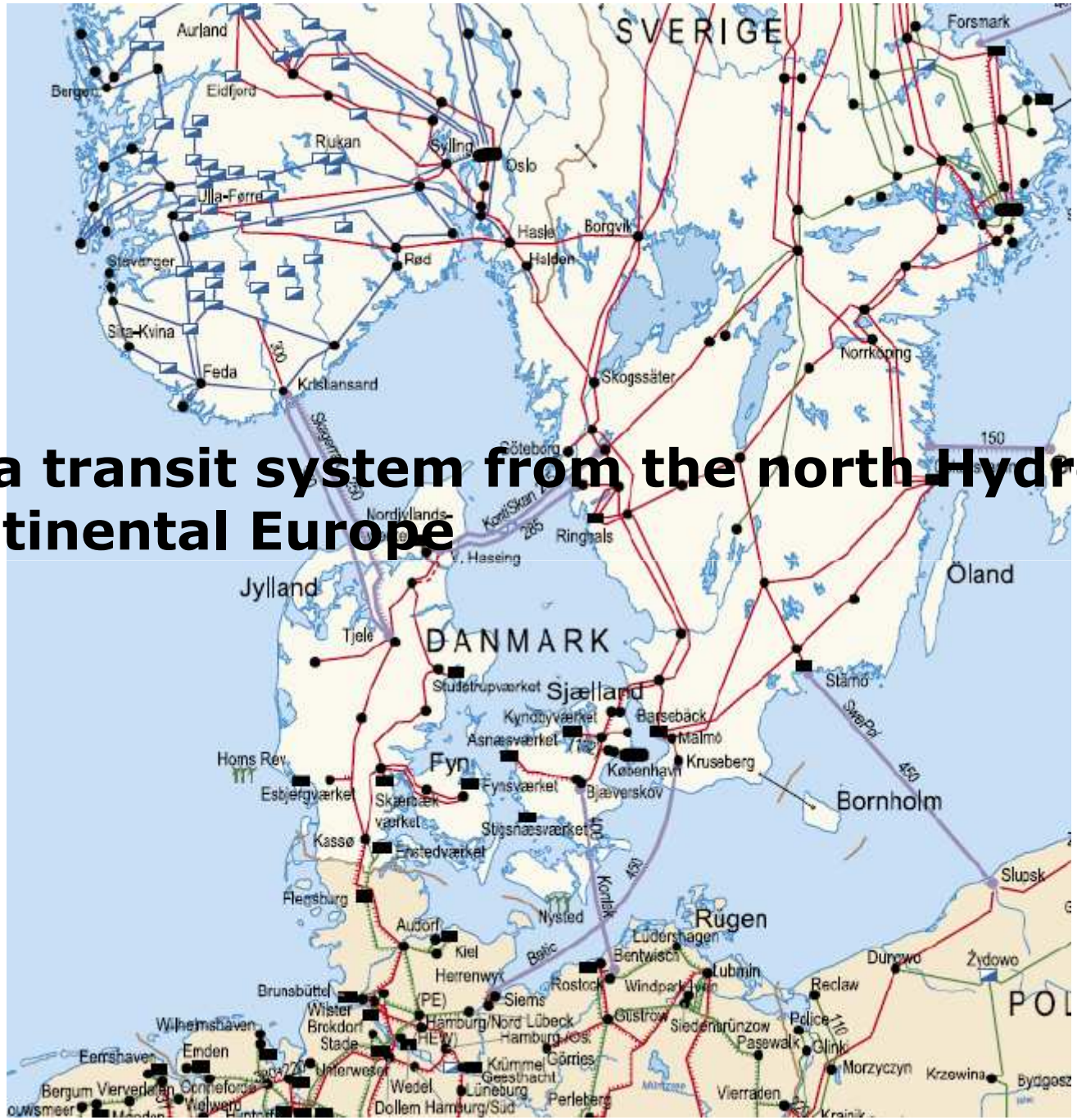
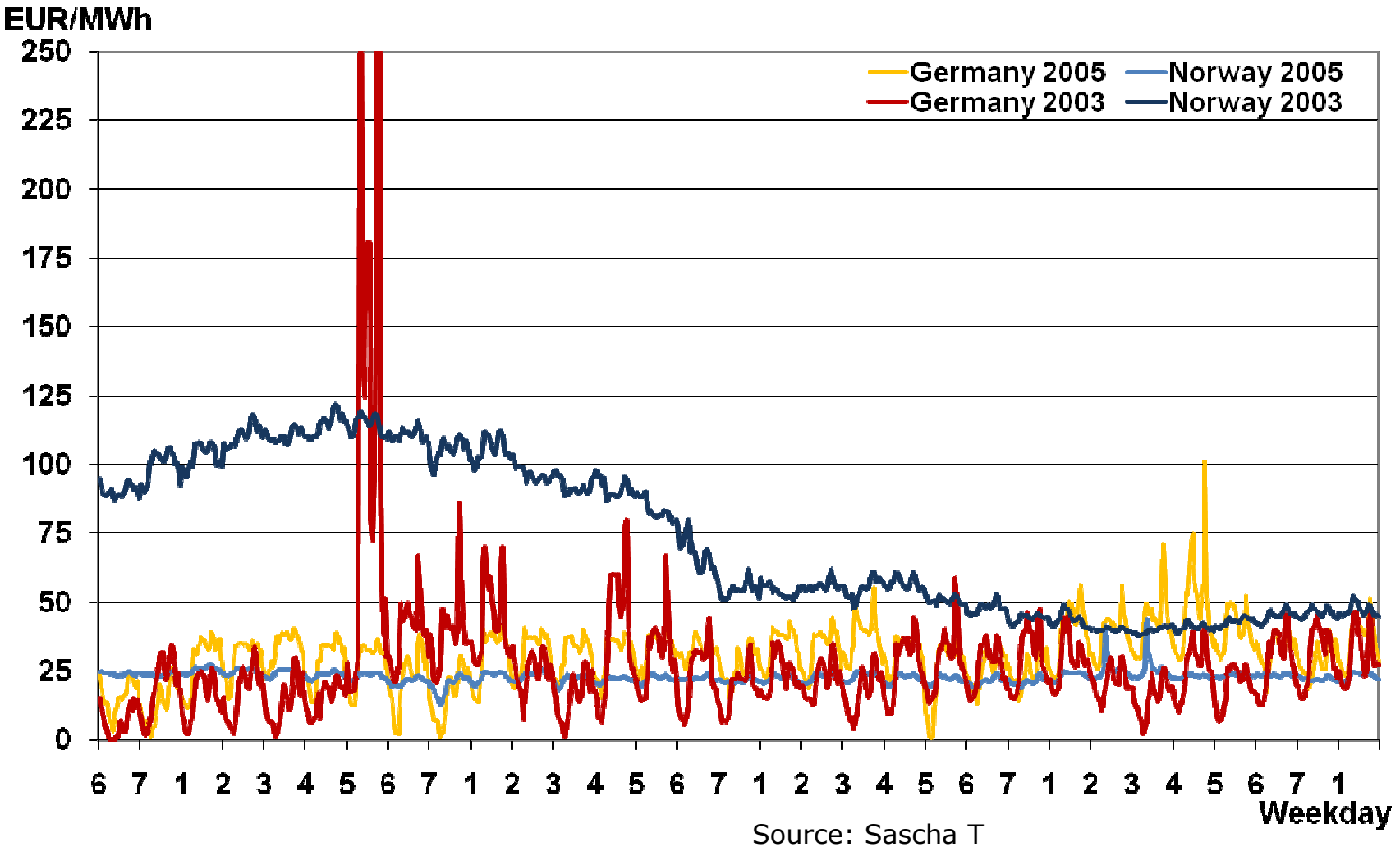


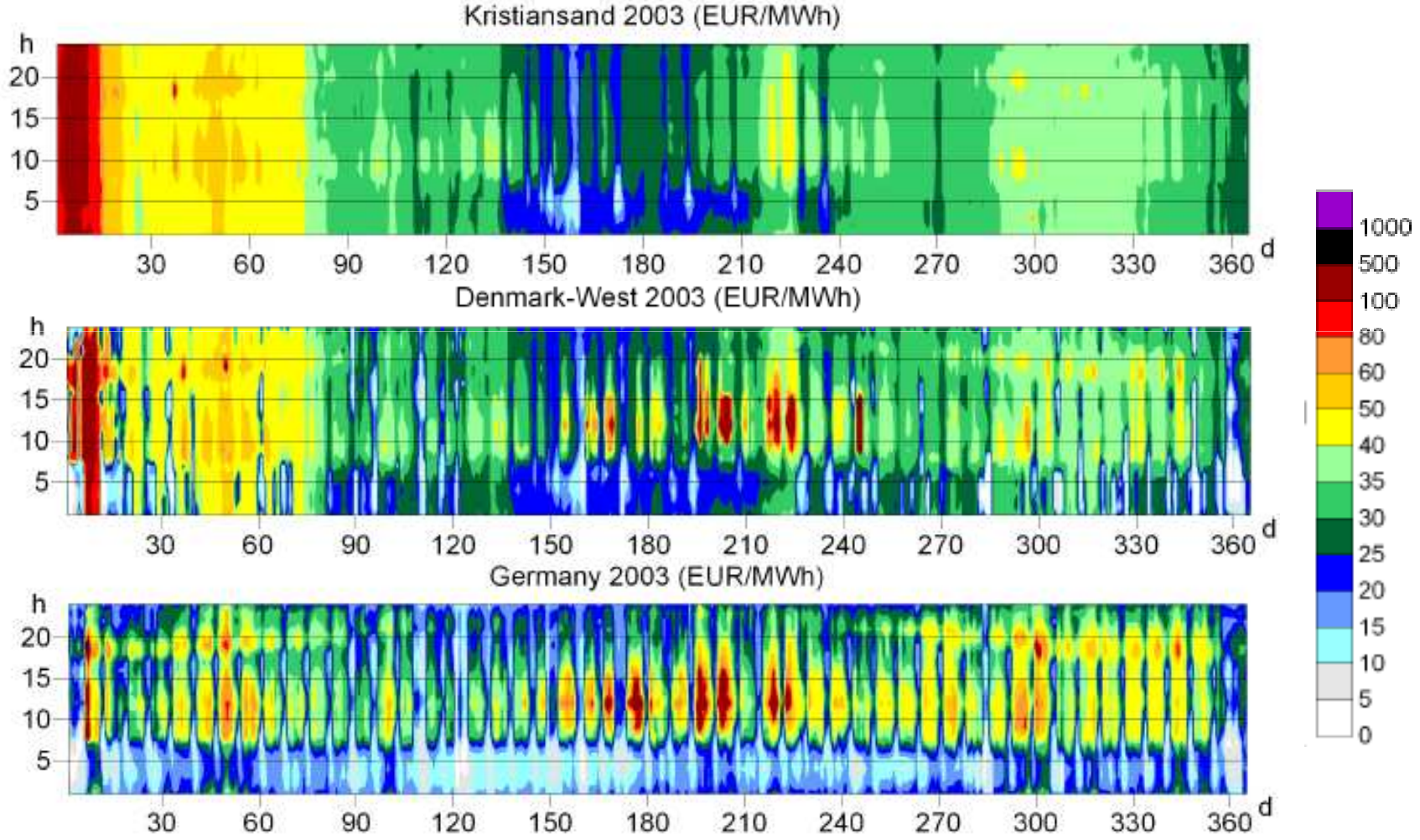
Figure: Nordel

January 2003/05 time series



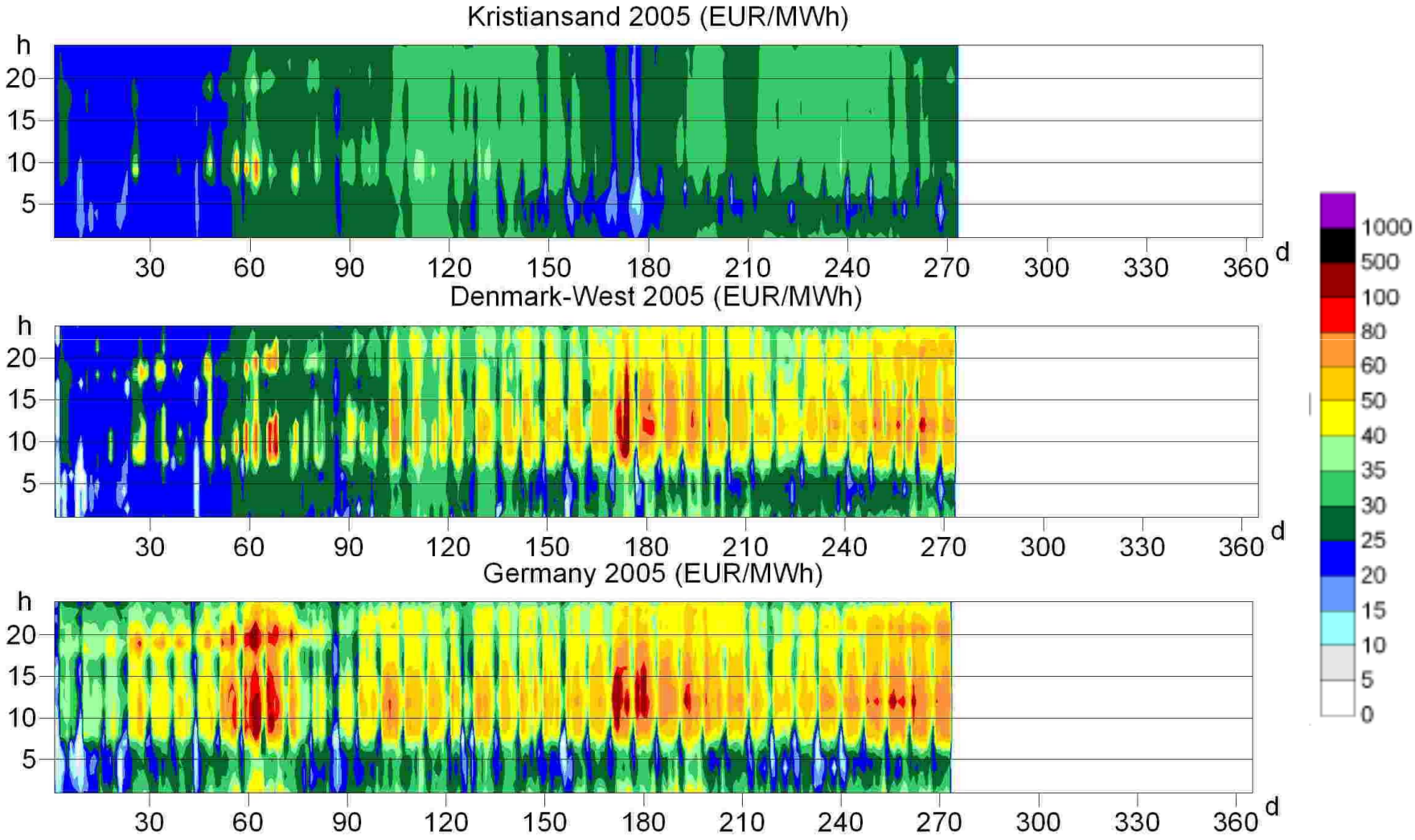
Source: Sascha T Schröder

2003 time series



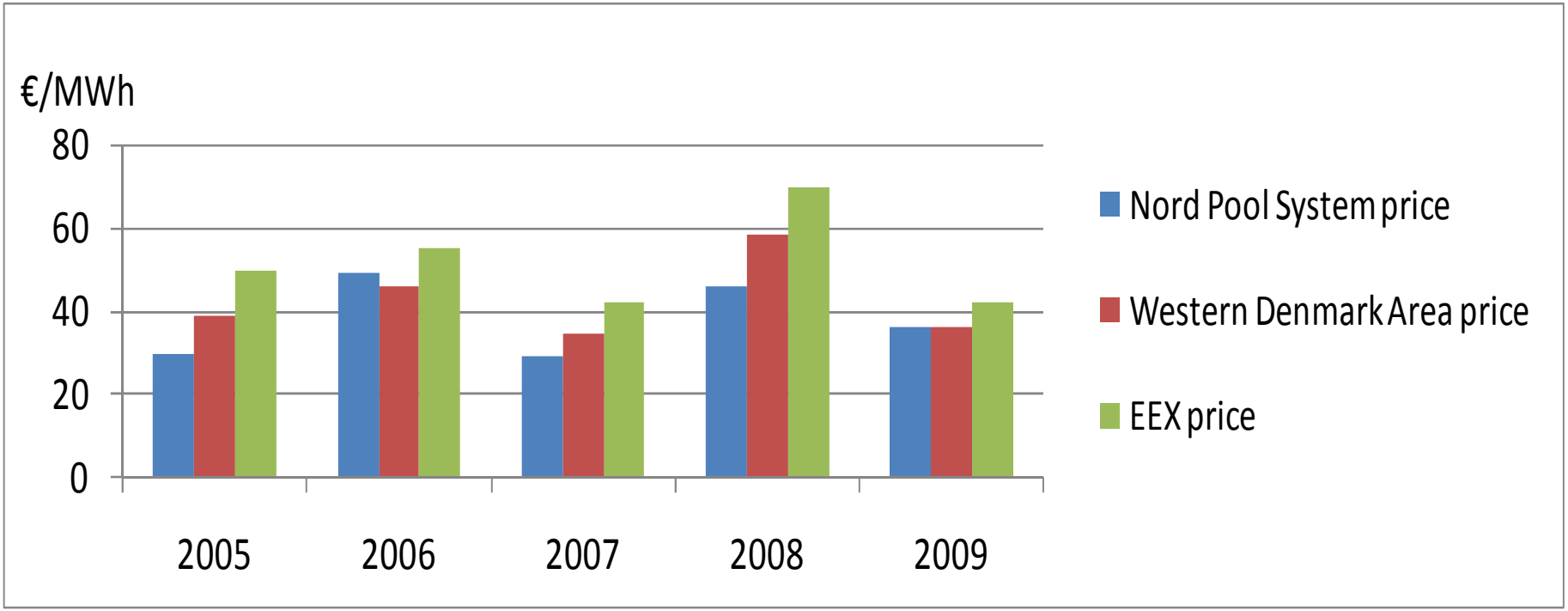
Source: Sascha T Schröder

2005 time series

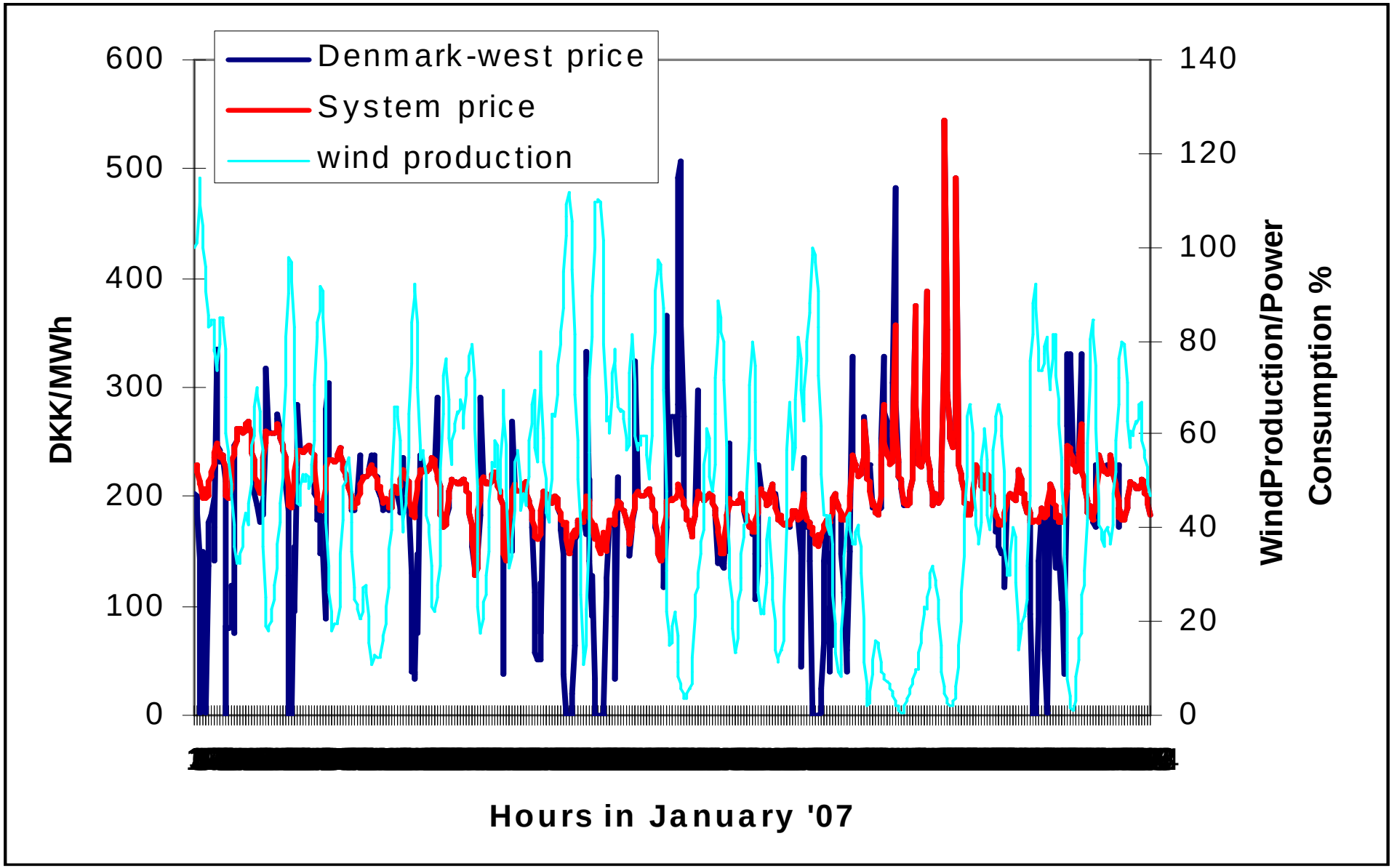


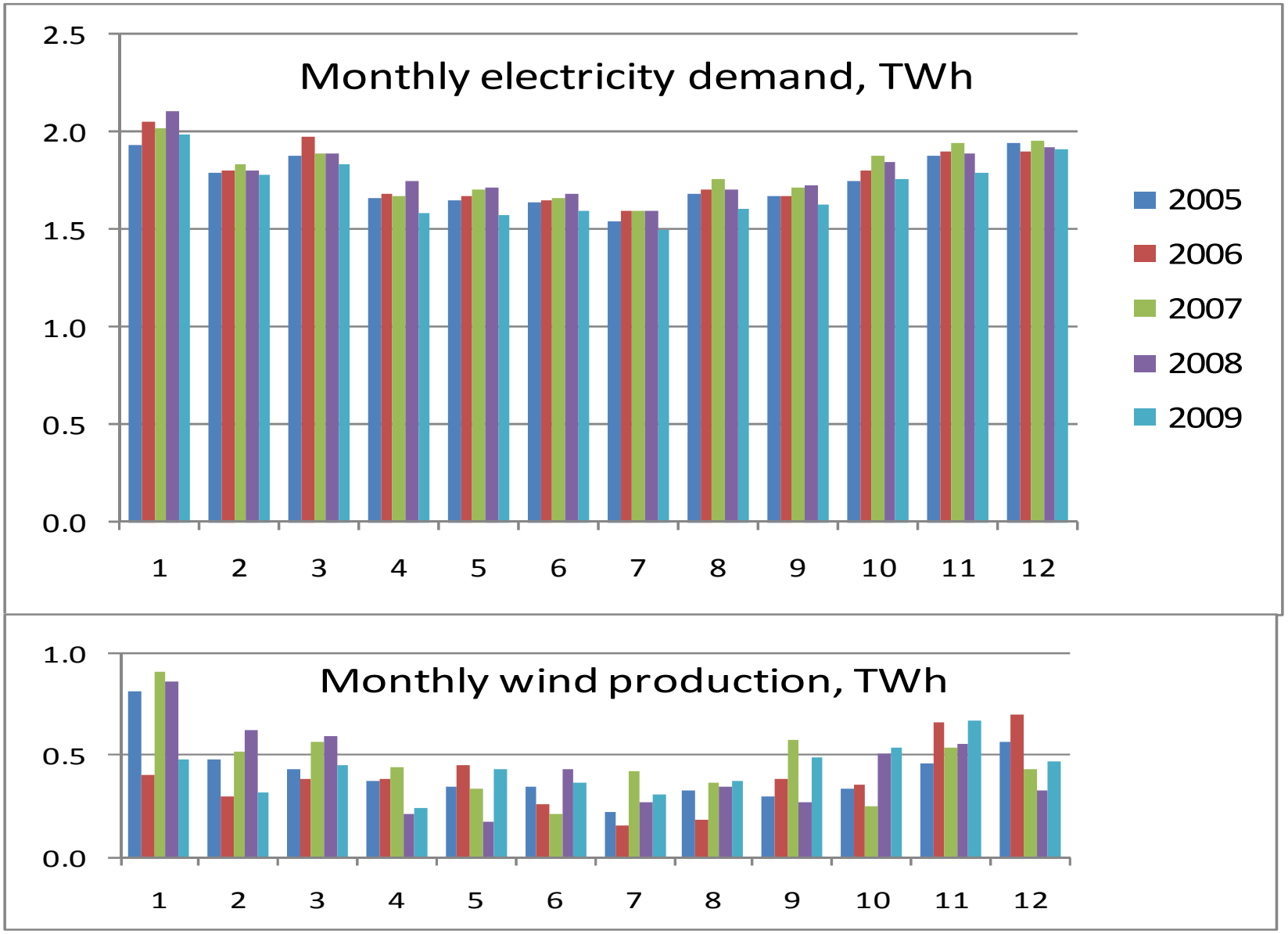
Source: Sascha T Schröder

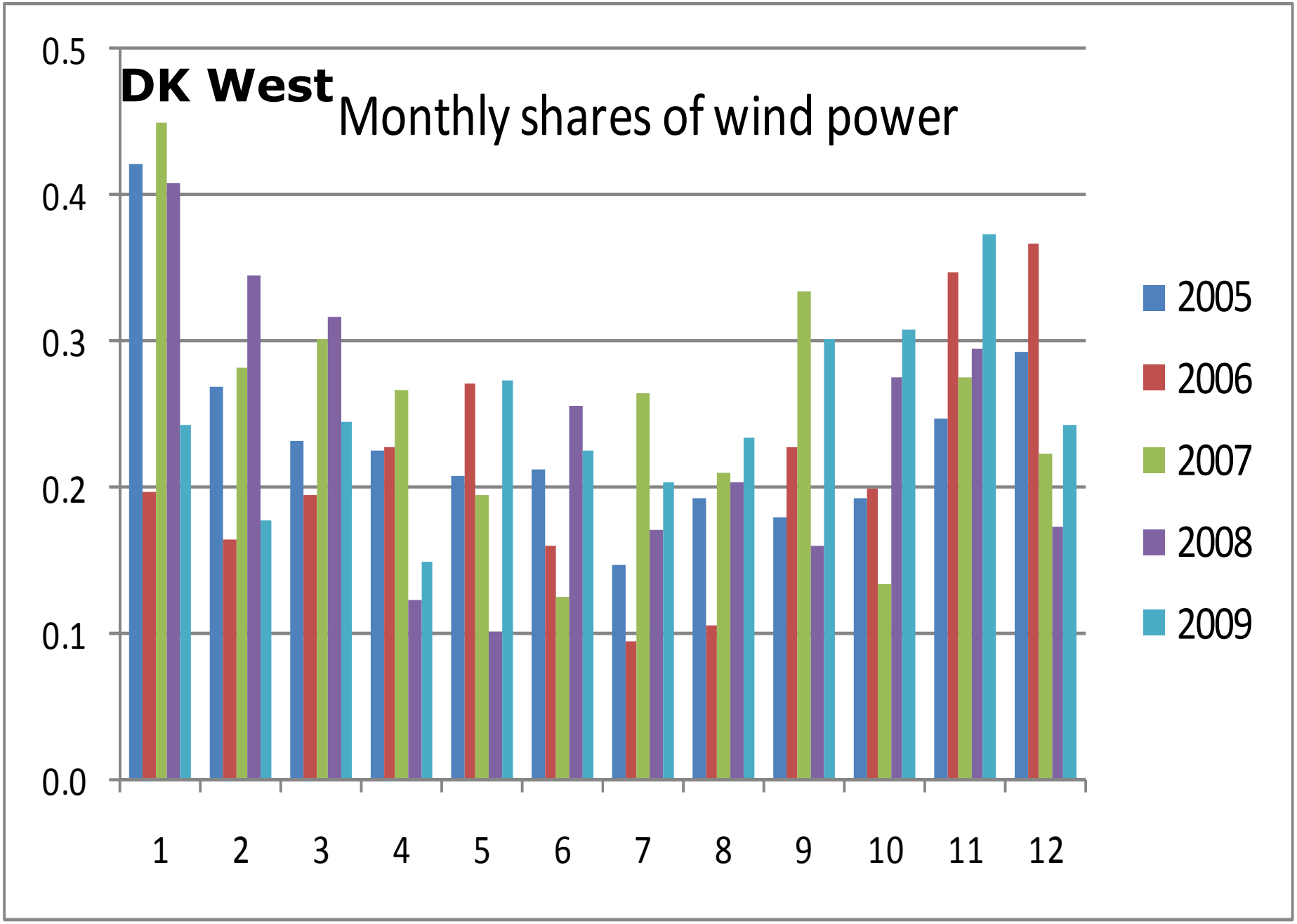
DK West as the price in the middle



Wind impact on Spot Price: DK West example



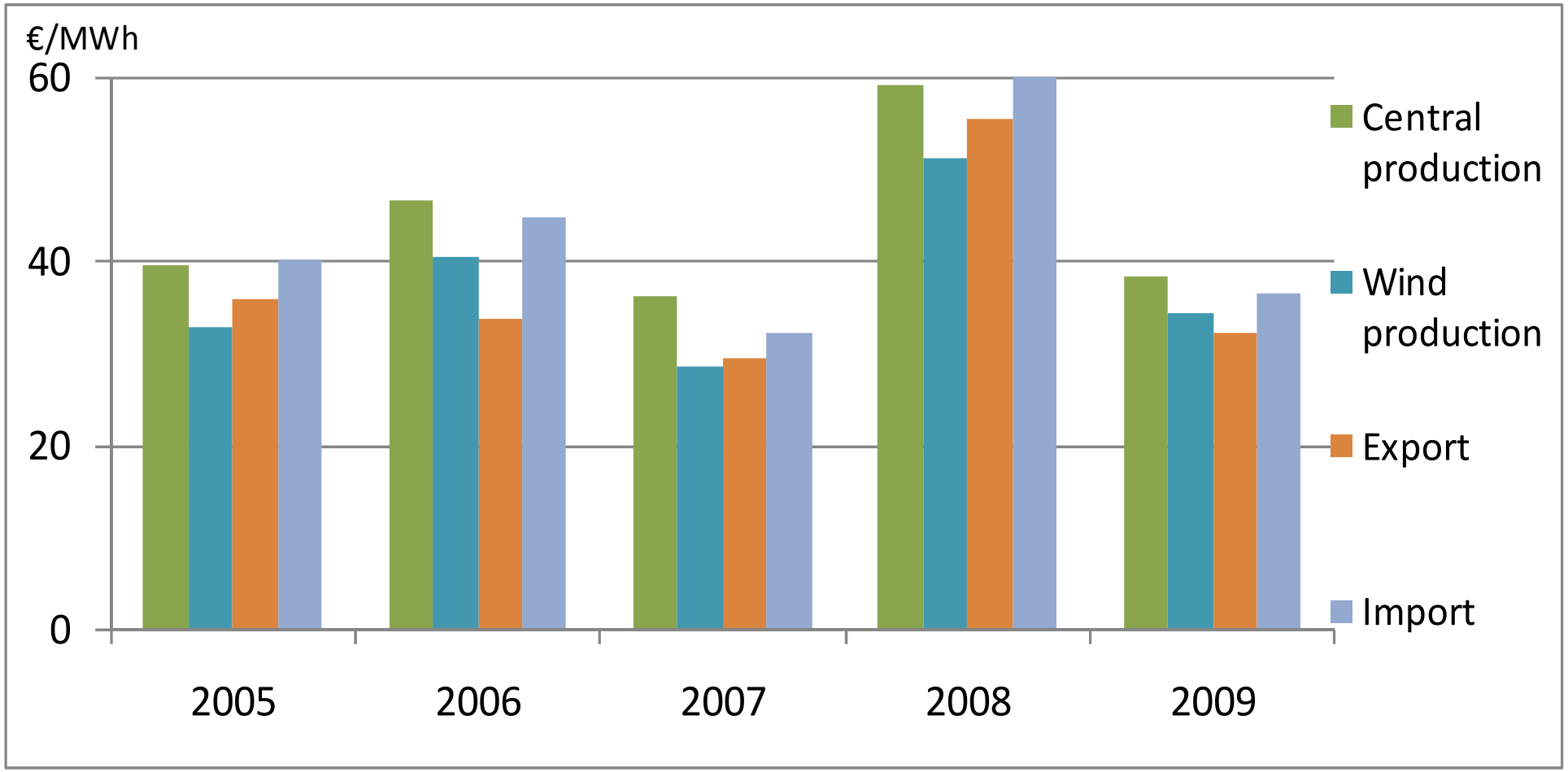

Monthly electricity demand, TWh
2.5
2.0
1.5
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
11
12
2005
2006
2007
2008
2009
Monthly wind production, TWh
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
11
12


DK West
Monthly shares of wind power
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
9
10
11
12
2005
2006
2007
2008
2009

DK West wind production and high prices caused by low wind

	2005	2006	2007	2008	2009
Wind production above 100 % of consumption, hours	42	26	50	43	33
Wind production below 10 % of consumption, hours	2887	3199	2946	3125	2778
Wind production below 1 % of consumption, hours	298	381	371	352	373
Above 100 €/MWh and wind production below 1 % of consumption, hours	9	0	13	14	0
12 or more consecutive hours with wind production below 1 % of consumption, events	6	13	9	7	8
Highest number of consecutive hours with wind production below 1 % of consumption	22	40	76	25	30

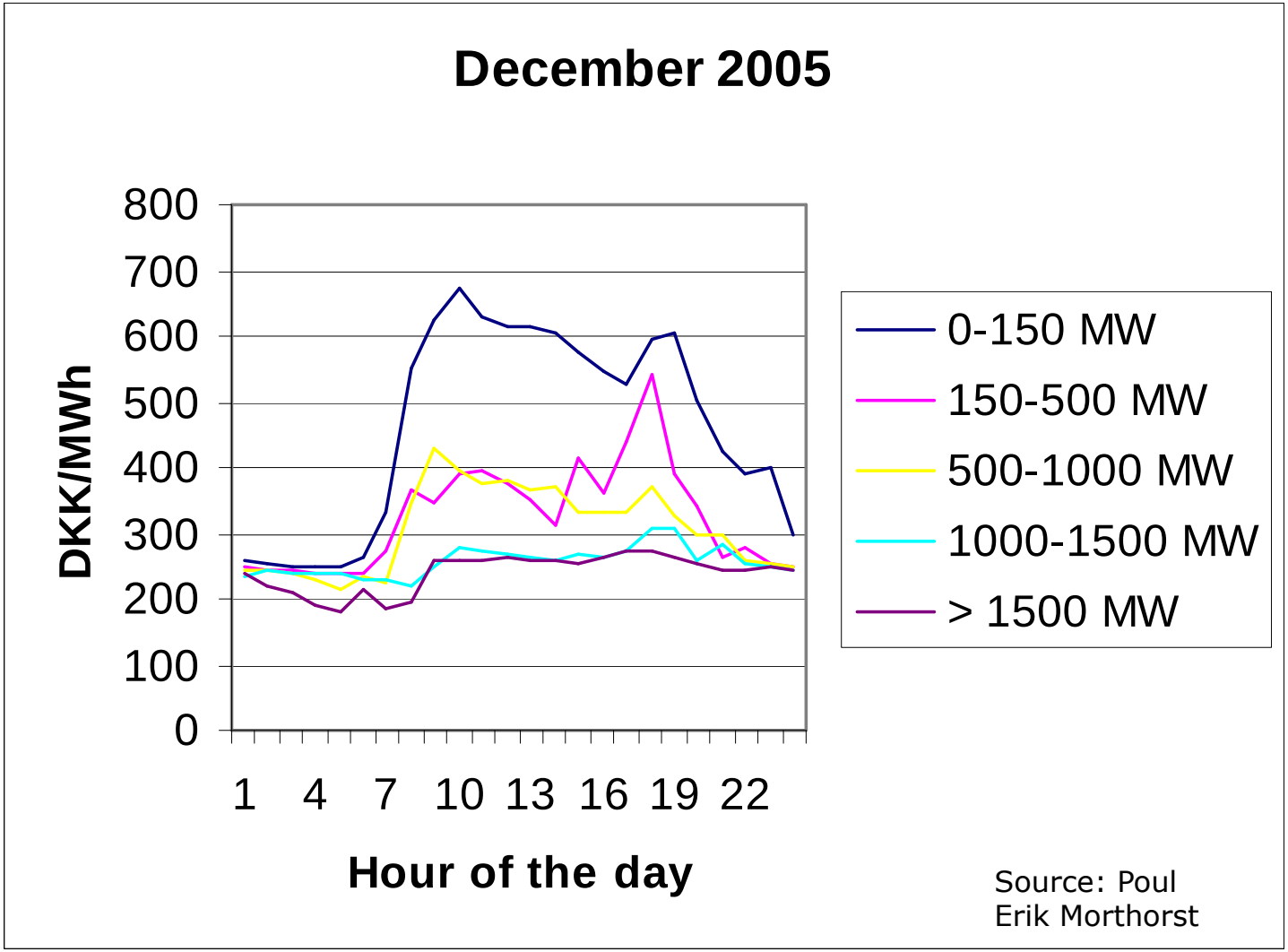
DK West hourly prices weighted with volumes of production and trade



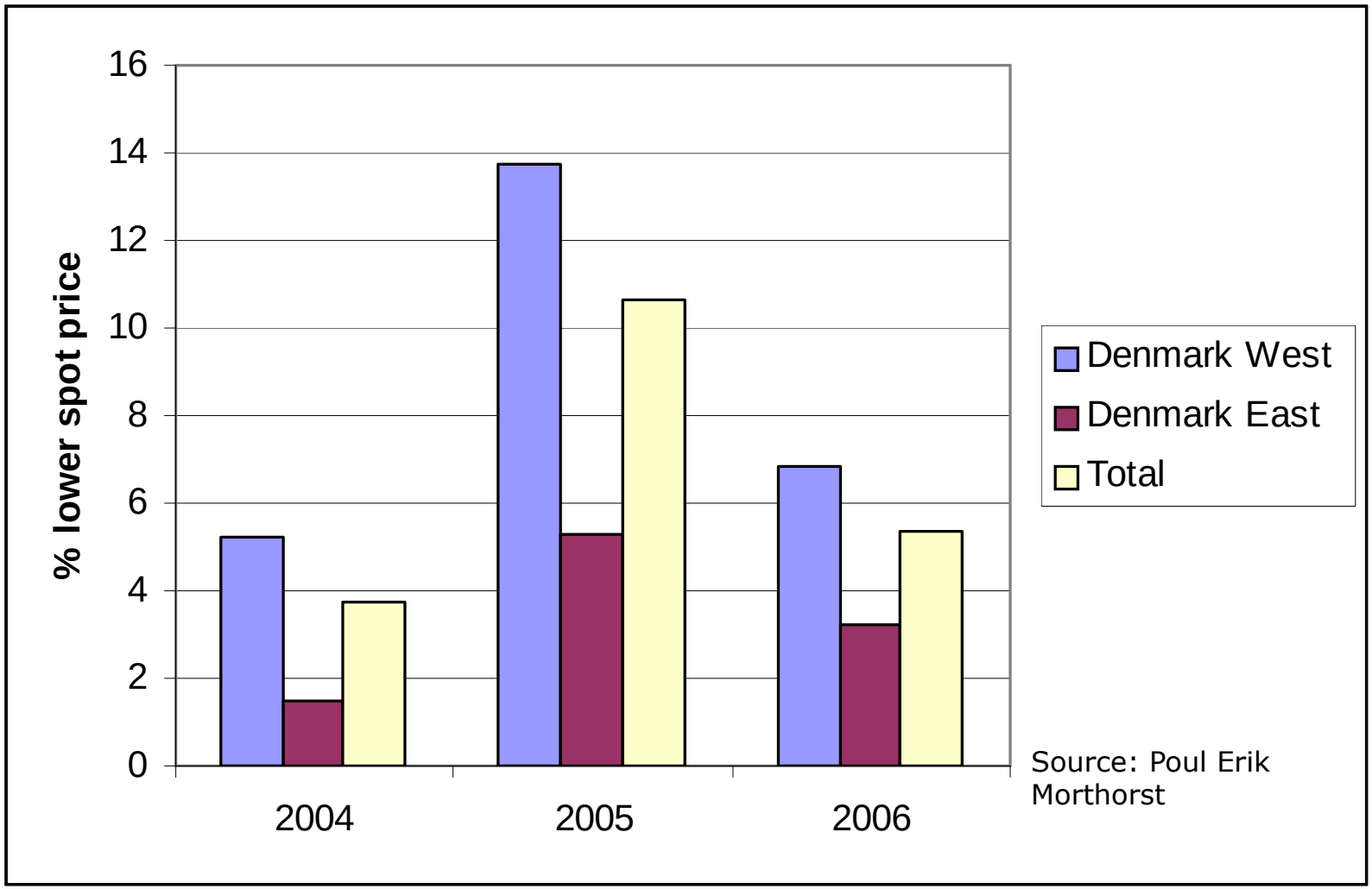
Example of price impact in a system with high intermittent shares and interconnection constraints

- Why is the low prices a problem?
- In a system with high intermittent shares there are unattractive low prices – from the generators view
- There is a lot of short term price variation
- There might be longer periods of high prices
- And the average spot market price is lower
- Especially market based wind generators will experience low prices

Impact at the Western-Denmark power market



Lower spot market prices: results for 3 years positive or negative?



Lower spot market prices and revenue for wind generators (calculated revenue)

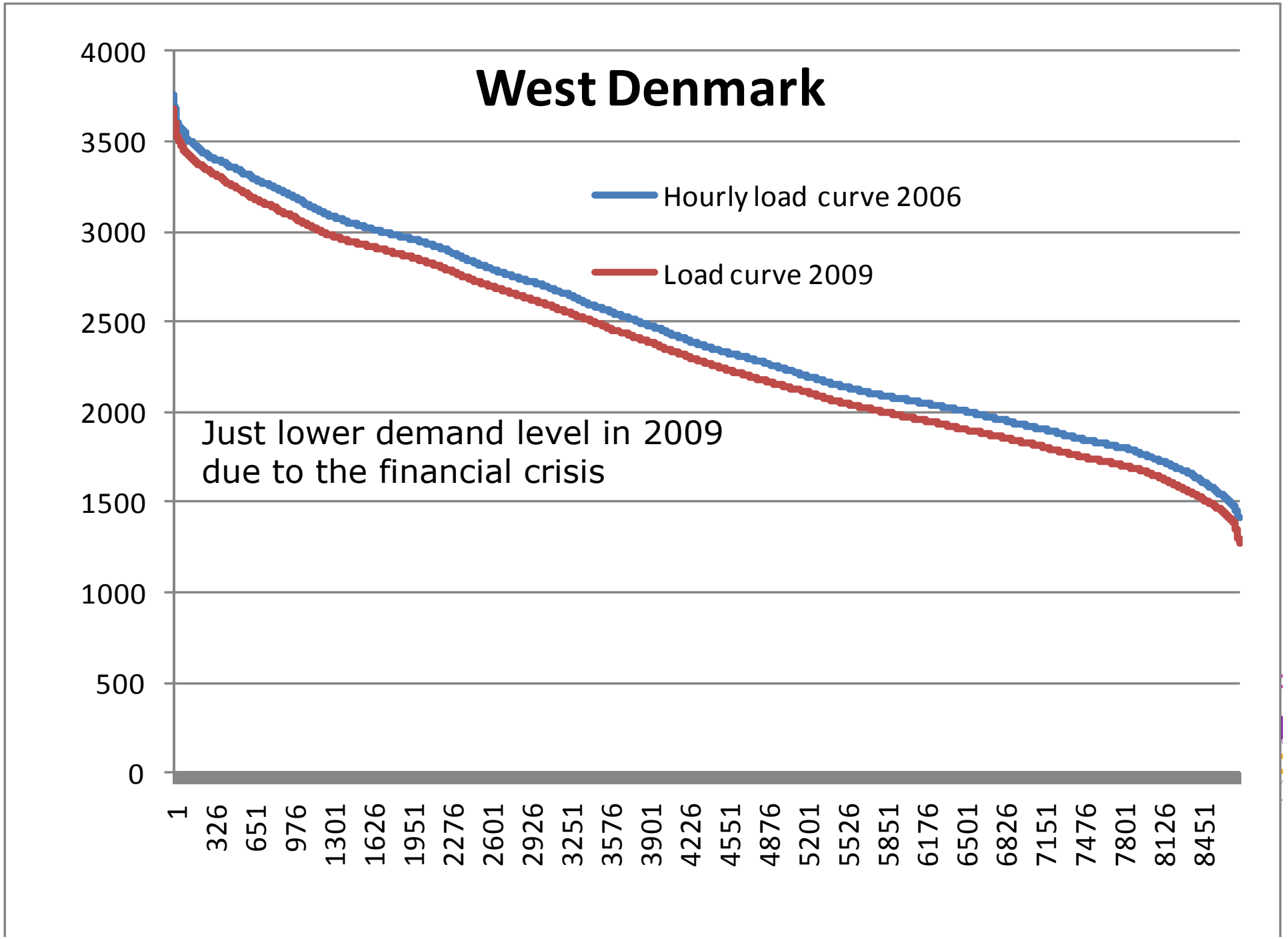
Table 1
Wind generators market-based revenues in the Western Denmark price area.

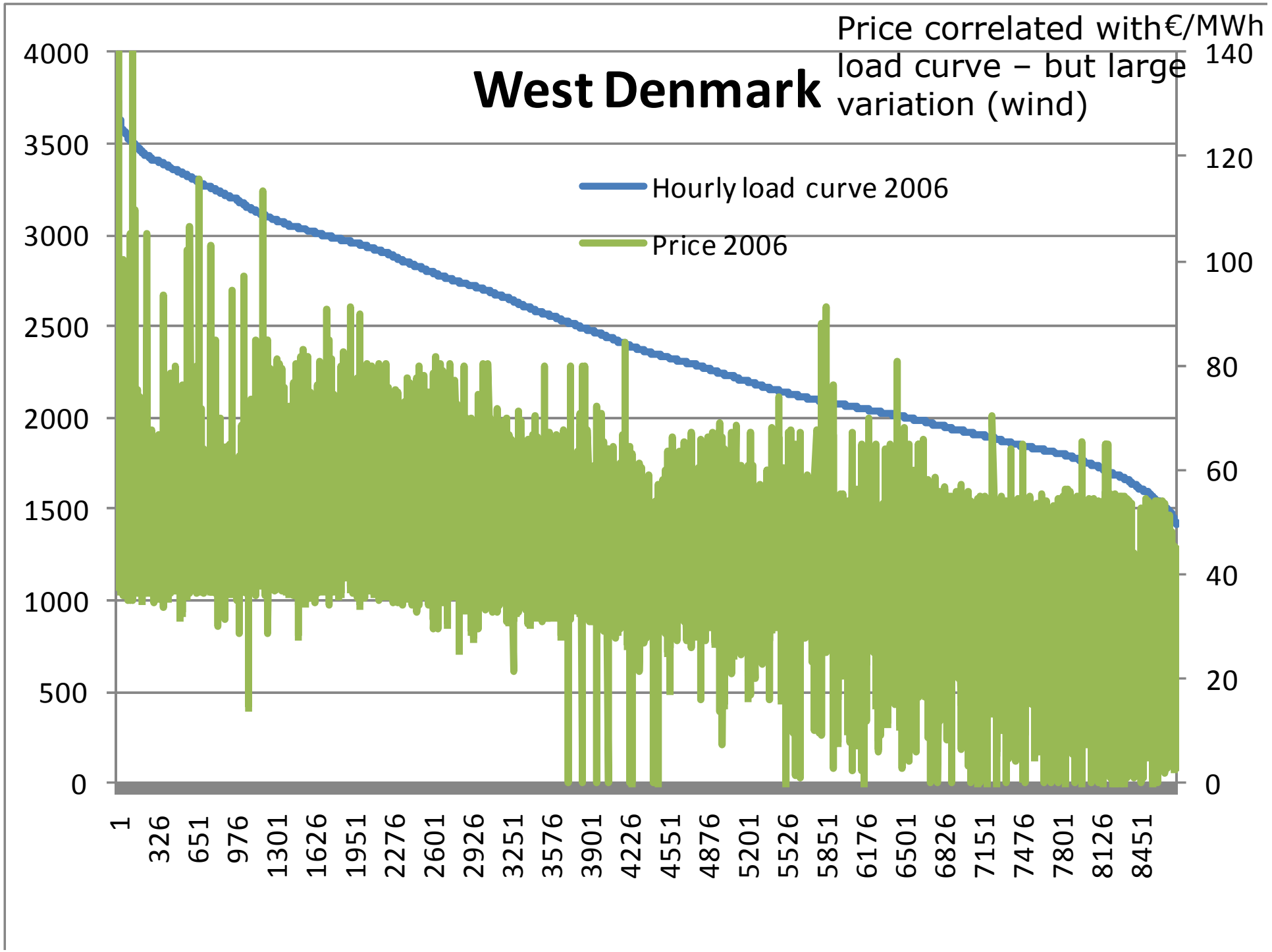
	Area Price €/MWh (direct average of hours)	Wind average price €/MWh	Difference €/MWh	Wind price relative to market (%)	Wind generation (GWh)	Potential loss mill. €
2006	44.19	40.54	3.64	92	4614	16.8
2007	32.40	28.66	3.74	88	5562	20.8
2008	56.42	51.20	5.22	91	5190	27.1

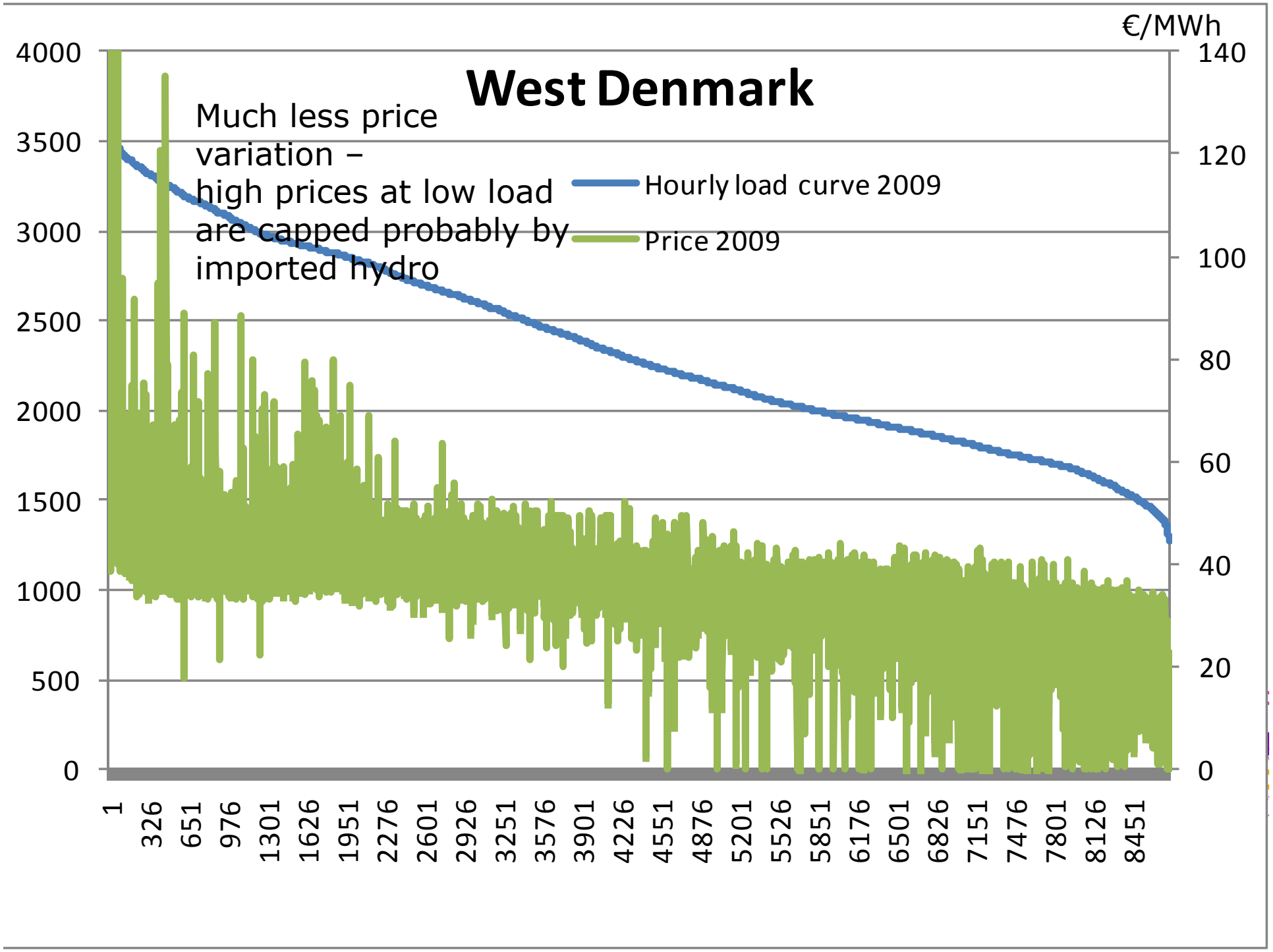
Wind generators thus receive a price that is around **10% lower** than the market average price

As the area price is already influenced by the wind generation the relative disadvantage of wind generators to conventional generators is larger

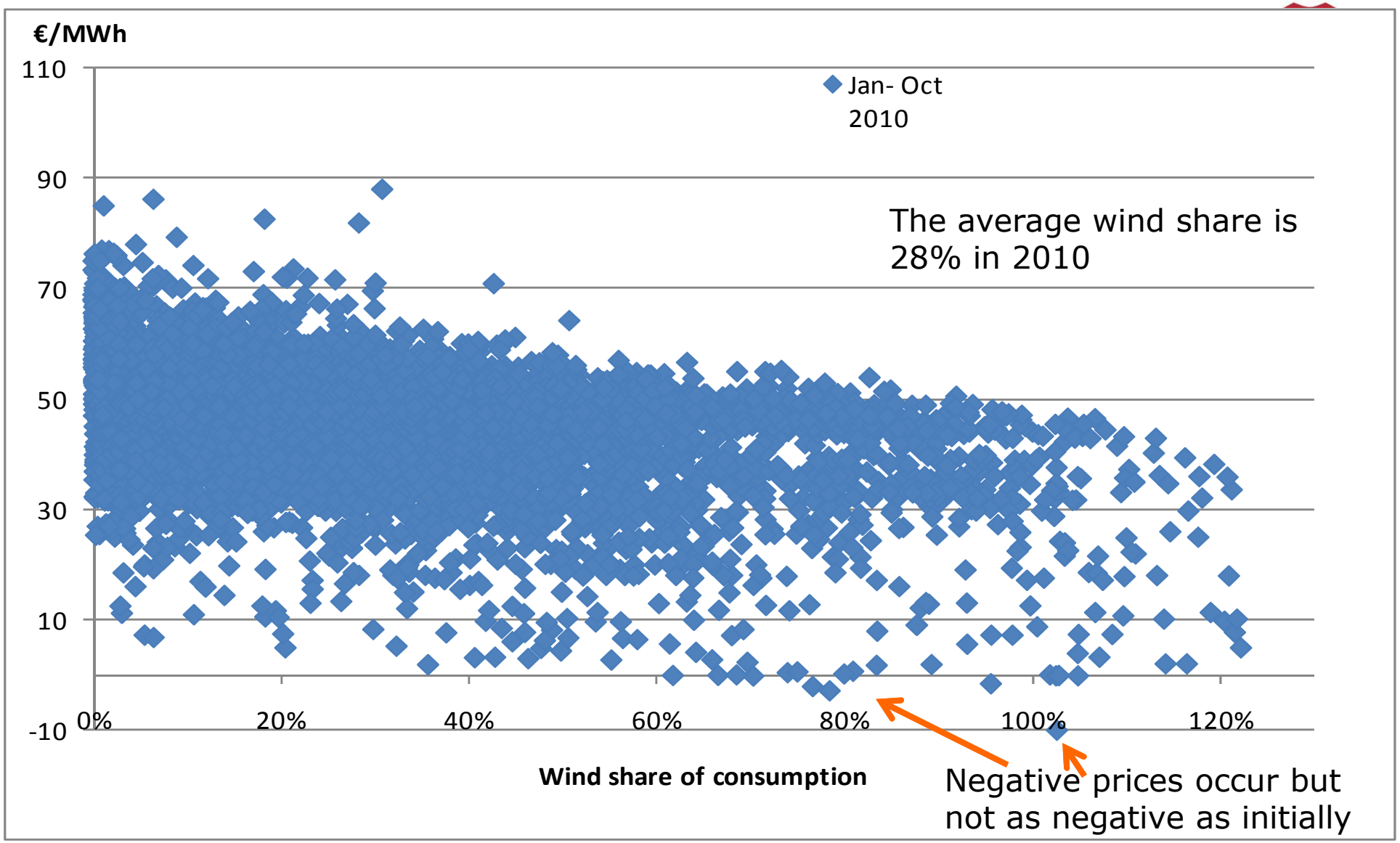
The large conventional generators have been estimated to receive an average revenue (price) that is **15-20% higher** than wind due to the controllability


West Denmark
Hourly load curve 2006
Load curve 2009
Just lower demand level in 2009
due to the financial crisis
4000
3500
3000
2500
2000
1500
1000
500
0
1
326
651
976
1301
1626
1951
2276
2601
2926
3251
3576
3901
4226
4551
4876
5201
5526
5851
6176
6501
6826
7151
7476
7801
8126
8451


West Denmark
Price correlated with load curve – but large variation (wind)
€/MWh
Hourly load curve 2006
Price 2006
4000
3500
3000
2500
2000
1500
1000
500
0
140
120
100
80
60
40
20
0
1
326
651
976
1301
1626
1951
2276
2601
2926
3251
3576
3901
4226
4551
4876
5201
5526
5851
6176
6501
6826
7151
7476
7801
8126
8451


West Denmark
Much less price variation – high prices at low load are capped probably by imported hydro
Hourly load curve 2009
Price 2009
€/MWh
4000
3500
3000
2500
2000
1500
1000
500
0
140
120
100
80
60
40
20
0
1
326
651
976
1301
1626
1951
2276
2601
2926
3251
3576
3901
4226
4551
4876
5201
5526
5851
6176
6501
6826
7151
7476
7801
8126
8451

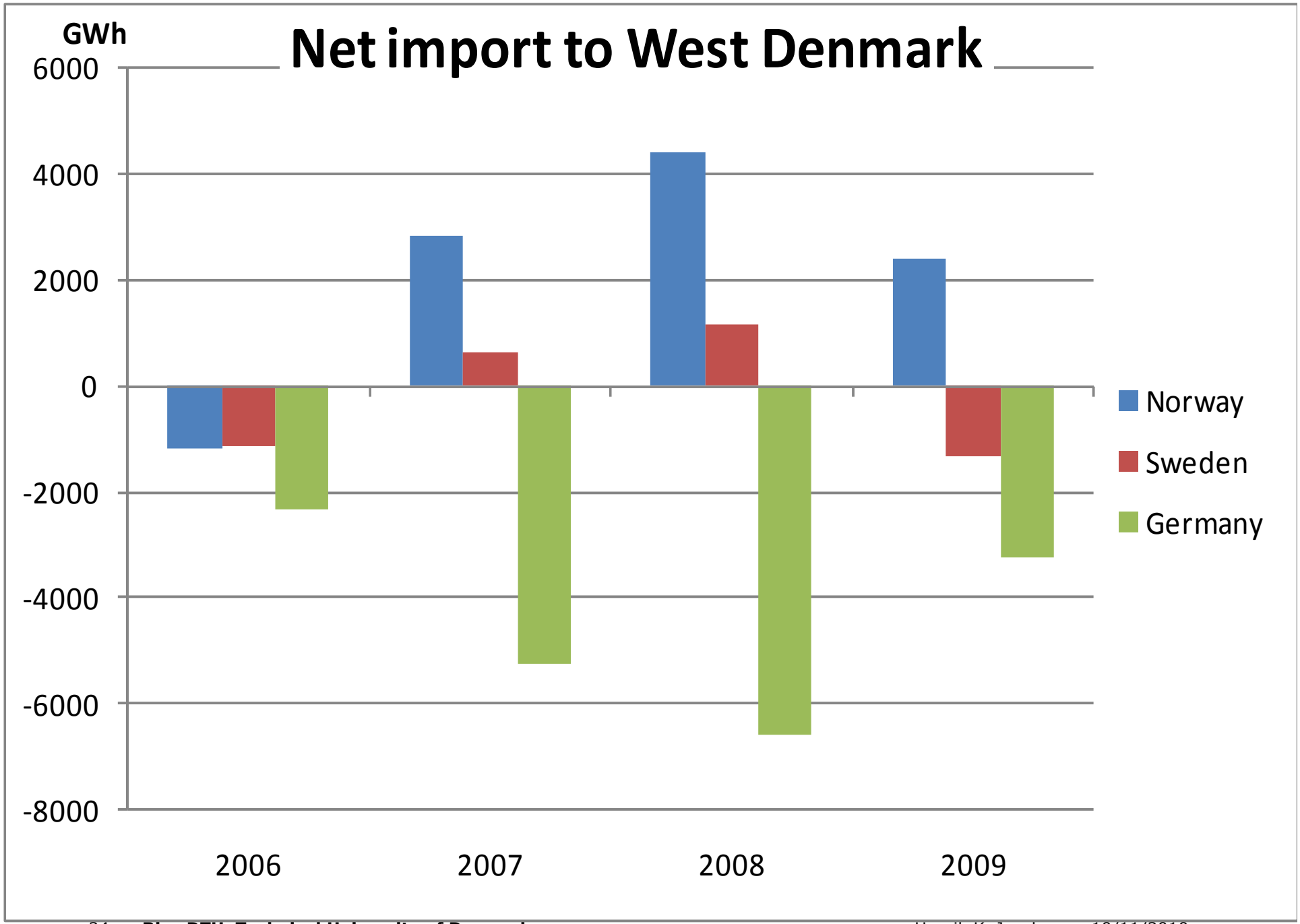
Jan-Oct 2010 price and wind generation DK West

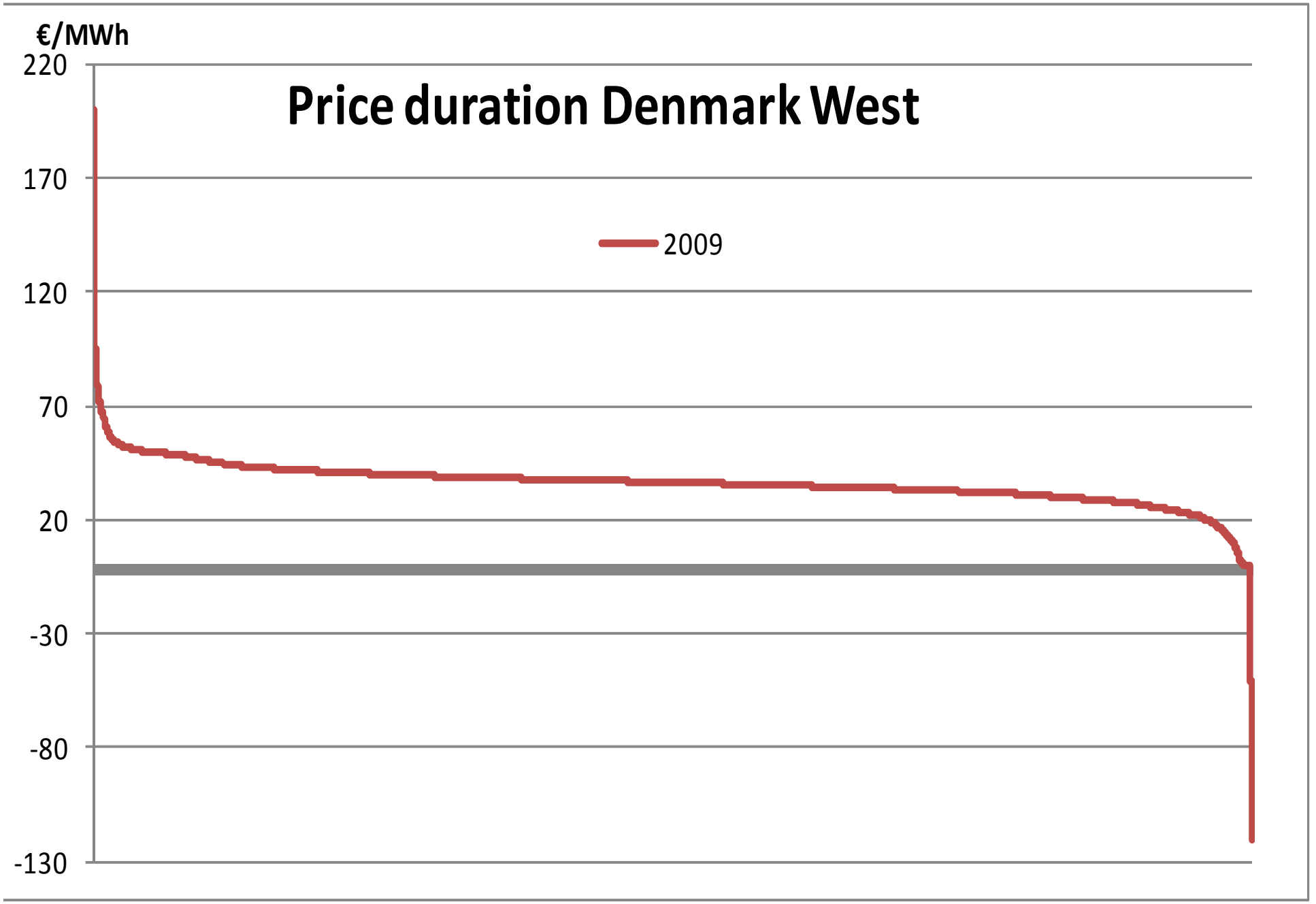


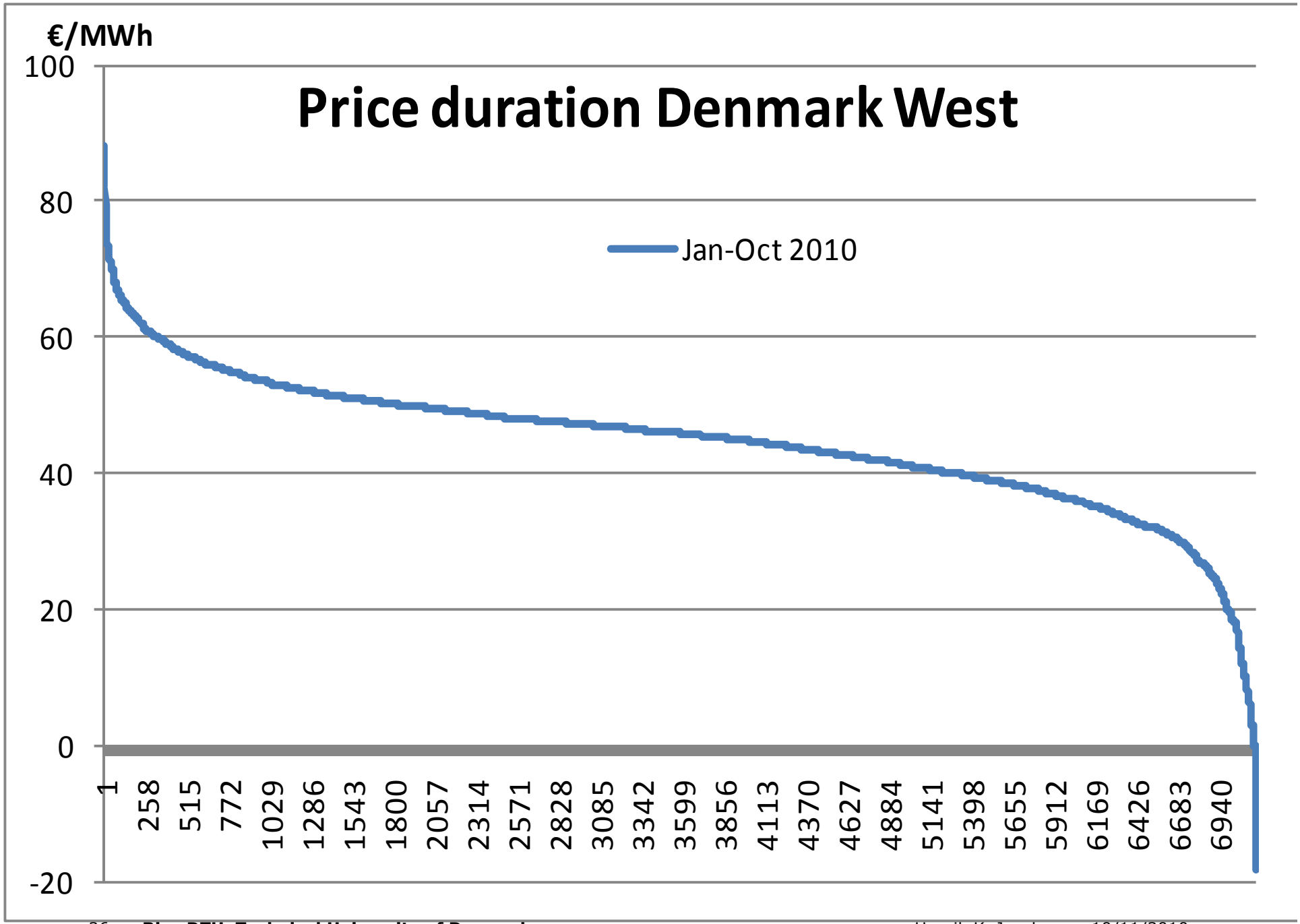
Interconnection capacities 2009

	Export capacity MW	Import capacity MW	Gross Export GWh	Gross Import GWh	Consumption GWh
DK-West - Norway	1000	1000	1448	3828	
DK West - Sweden	740	680	1985	667	
DK-West - Germany	1500	950	4960	1710	
Total	3240	2630	8394	6205	20550

Wind generation 5123 GWh


Net import to West Denmark
GWh
6000
4000
2000
0
-2000
-4000
-6000
-8000
2006
2007
2008
2009
Norway
Sweden
Germany


€/MWh
220
170
120
70
20
-30
-80
-130
Price duration Denmark West
2009


€/MWh
Price duration Denmark West
Jan-Oct 2010
100
80
60
40
20
0
-20
1
258
515
772
1029
1286
1543
1800
2057
2314
2571
2828
3085
3342
3599
3856
4113
4370
4627
4884
5141
5398
5655
5912
6169
6426
6683
6940

Negative prices

- 2009 had 9 hours negative prices
- 2010 shows also just 9 hours with negative price

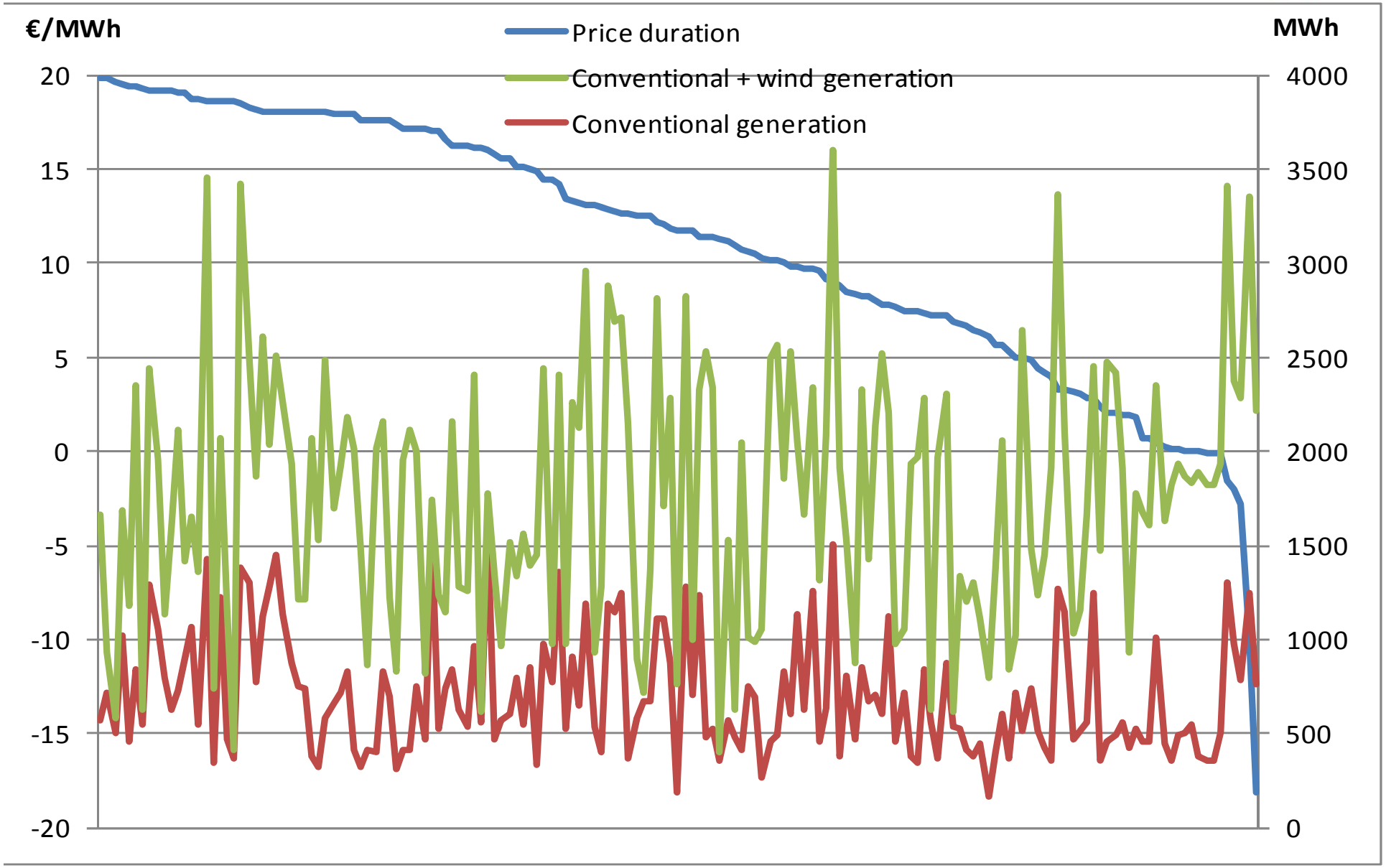
- Only 165 hours below 20€/MWh in 2010

- Conventional generation operating at minimum 350-400 MW during low prices

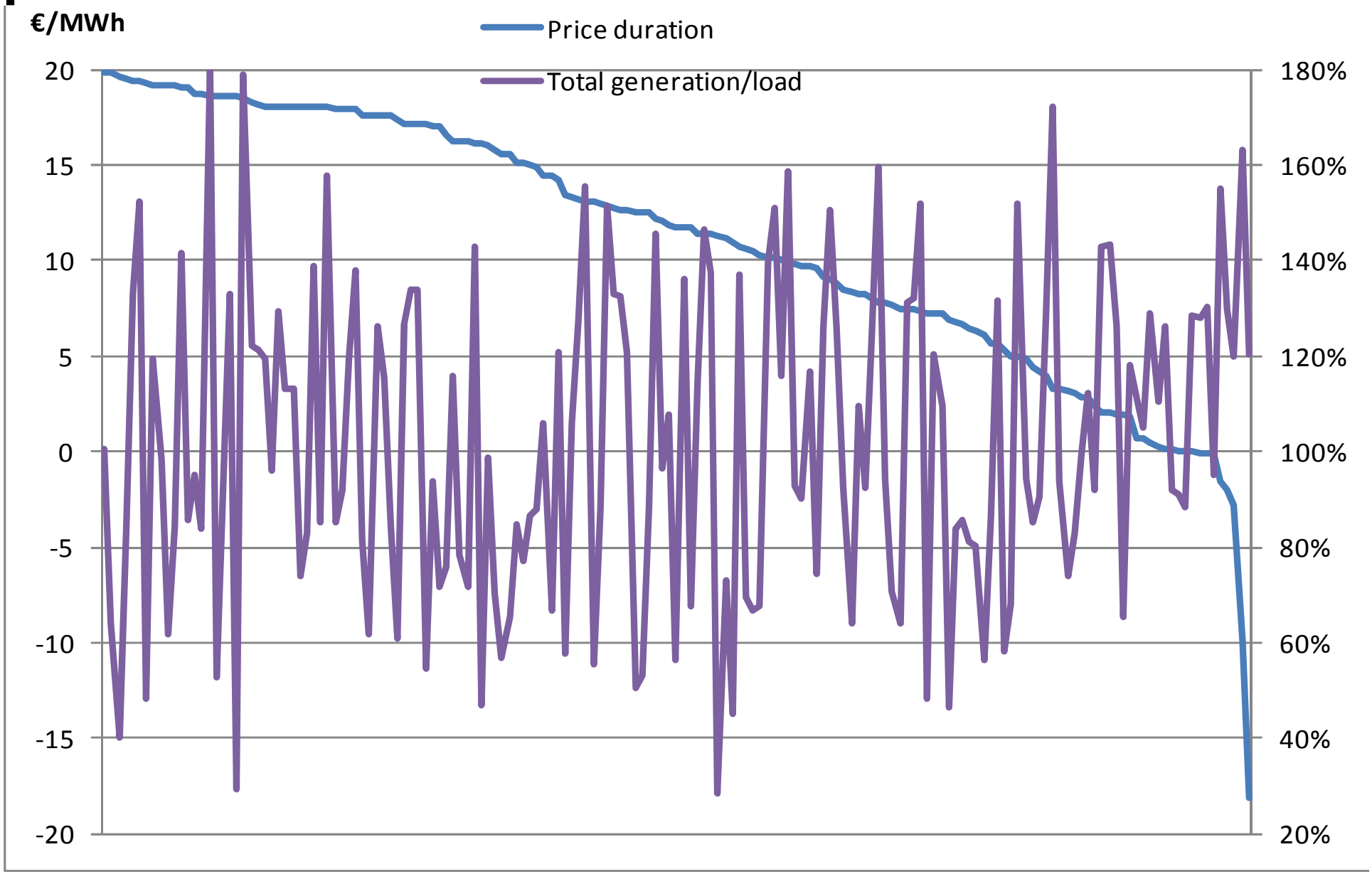
- Exports considerable when prices are negative, but mostly to Norway

- For all negative prices in 2009 import from Germany and export to Norway

Price duration 165 hours with lowest prices in 2010



Generation to load ratio for 165 hours with lowest prices in 2010



Conclusion: How large are the two short term price effects of wind in Denmark?

1. Reduced prices due to wind power
   - DK West prices are reduced 5-13%
   - The system price in the Nordic area has only been marginally reduced due to the wind power
   - The revenue corresponding to the prices at wind power generation times are almost 10% lower than the average prices in West Denmark
2. Increased price volatility due to wind power
   - Price volatility is probably not higher because of the additional wind power capacity being added
   - but volatility might increase as conventional capacity is now being decommissioned (one coal block at Ensted)
3. Large interconnection capacity to Norwegian hydro is the major explanation why the integration of 25-28% wind generation has caused relatively few problems in West Denmark

Thank you for your attention!

Henrik Klinge Jacobsen
jhja@risoe.dtu.dk
+45 4677 5109

Risø National Laboratory for Sustainable Energy
Technical University of Denmark – DTU
Systems Analysis Division
Building 110, P.O. Box 49
DK-4000 Roskilde, Denmark
www.risoe.dtu.dk